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VTOL TRANSPORT AIRCRAFT

Comparative Study

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STOL CAPABILITIES
VERTOL REPORT NO. R-82

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VERTOL Aircraft Corporation

SEP 9 1957

formerly - Piasecki Helicopter Corporation

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Comparative Study of Various Types of VTOL Transport Aircraft

STOL CAPABILITIES REPORT R-82

Vertol Aircraft Corporation Morton, Pennsylvania

ONR ARMY

A Combined

Research and Development Program

Contract NONR 1681(00)

PREPARED BY
R. J. HARRIS

Supervised by W. Z. Stepniewski
W. Z. STEPNIEWSKI Chief - R&D

Approved by L. L. Douglas
L. L. DOUGLAS Vice Pres.- Engineering

JULY 13, 1956

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I. SUMMARY

In connection with Contract Nonr 1681(00), received by Vertol Aircraft Corporation in May 1955 from the Office of Naval Research, it was decided to undertake a study of the increased gross weight potential available to VTOL transport aircraft when operating with running take-offs.

This study was conducted to determine the overload gross weights that can be attained as a function of ground distance required to clear a 50 foot obstacle.

Specifically this study was made to investigate the STOL potential of the Tilt Wing Propeller VTOL Transport design, since it was the optimum aircraft for the specified mission (Ref. a). The study was confined to the take-off regime only since the prime mission was that of an assault transport and it was assumed that landings would be effected from a vertical attitude.

In performing the running take-off calculations, it was assumed that fuselage attitude remains horizontal during the climb out phase of the maneuver. It was also assumed that flaps would be available for the ground roll and climb portion of the take-off, and an optimum slot and slat combination would also be available for climb out.

For the particular aircraft at a given overload gross weight, it was apparent that two basic factors influenced the total take-off distance: one, the wing tilt angle and two, the minimum forward speed of flight.

It was decided to investigate several values of wing tilt angles over a wide forward speed range in order to get the rate of gross weight build-up. In this way an upper weight limit (from an aerodynamic point of view) could be established.

The results of this study are presented graphically (Figures II and III) in terms of ground roll and total take-off distance as a function of gross weight and wing tilt angle. This was done for a pressure altitude of 6,000 feet at 95°F and for sea-level standard conditions in order to show the load carrying capabilities of this aircraft.

III. DESCRIPTION OF METHOD & RESULTS

A. Ground Roll

The propeller thrust as a function of several assumed free-stream or ground velocities was calculated with the aid of reference (c).

It was then necessary to calculate, for each of the assumed velocities, the velocity increment in the slipstream due to the propeller thrust. This was accomplished as outlined in reference (d) where:

$$v = 1/2\left[\sqrt{V^2 + \frac{2T}{\rho \frac{\pi D^2}{4}}} - V\right] \qquad (1)$$

and T is the thrust developed per nacelle and D is the propeller diameter.

It was assumed that the thrust axis coincides with the wing chord and that the entire wing is immersed in the slipstream. With these assumptions the wing angle of attack for any spanwise station becomes a function of the wing tilt angle as follows, (see Figure 1):

$$\delta = \tan^{-1} \frac{v \cos \phi}{V + v \sin \phi} \qquad (2)$$

where ϕ is the wing tilt angle from the vertical and δ is the angle the resultant velocity makes with respect to the free-stream velocity.

The actual angle of attack is then

$$\alpha = 90 - \phi - \delta \qquad (3)$$

and the resultant velocity is

$$V_R^{\ 2} = \left(V + v \sin \phi\right)^2 + \left(v \cos \phi\right)^2 \qquad (4)$$

The basic section is an NACA 4415 airfoil with a $C_{L\,max}$ of 1.3, and it is assumed to be equipped with a slotted flap such that

$$E = \text{flap chord/wing chord} = .25 \qquad (5)$$

and that a ΔC_L of .70 may thus be realized with this combination.

From reference (a), it was calculated that 22° of flap deflection would supply the assumed ΔC_L value as follows:

$$\Delta C_L = \delta_F \left(a_2^{1} - K \cdot \delta_F\right) \qquad (6)$$

where: a^1_2 and K are functions of $\frac{\text{Flap Chord}}{\text{Wing Chord}}$ ratio and δ_F is the required flap deflection angle.

It was then necessary to modify the C_D for the wing to include the additional drag due to this flap deflection as per reference (e) as follows:

$$C_{DF} = C_D + \frac{\left[\left(C_L + \Delta C_L\right)^2 - C_L^2\right]}{\pi AR} + \Delta C_{D_0} \qquad (7)$$

where ΔC_{D_0} was calculated from information of reference (f) for 22° of deflection with a slotted flap.

It was then possible to calculate the lift and drag acting on the wing-flap combination for any wing tilt angle.

The parasite drag acting on all parts of the aircraft less the wing was calculated in the usual manner.

The only remaining force acting on the aircraft during ground roll is friction and it is defined as follows:

$$F_F = \mu \left[W - L\cos\delta + D\sin\delta - T\cos\phi \right] \tag{8}$$

where μ is a friction coefficient of .2

At any given instant all forces acting on the aircraft may be summed up as follows:

$$\Sigma F_x = T\sin\phi - D\cos\delta - L\sin\delta - F_F \tag{9}$$

$$\Sigma F_y = T\cos\phi + L\cos\delta - D\sin\delta - W \tag{10}$$

The next step was to check the rate of gross weight increase as a function of forward speed for several values of wing tilt.

This was done by assuming 25, 35 and 45 degrees of wing tilt and summing up the net lifting force as upward speed increased up to a value which brought the wing to its $C_{L\,max}$.

For 6,000 ft. pressure altitude @ 95°F, this phase of the study showed that the VTOL design gross weight of 90,000 lbs. could be surpassed with the aid of a short take-off run by the following combination of parameters:

(a) At 45° of wing tilt gross weight increased to 96,000 lbs. for 340 ft. ground roll.

(b) At 35° of wing tilt gross weight increased to 103,500 lbs. for 750 ft. ground roll.

(c) At 25° of wing tilt gross weight increased to 120,000 lbs. for 1,810 ft. ground roll.

This analysis indicated the shortest ground roll distance could be attained with 45° of wing tilt for which a 7% increase over design VTOL gross weight is obtainable. For 35° of wing tilt, the gross weight could be increased by 15% and for 25° of wing tilt by 33%. (see Figure II) Of course, the lower tilts required longer ground runs.

For sea-level standard conditions VTOL gross weight is 104,000#. The trend of gross weight for STOL operation is shown for the following parameters:

(a) At 45° of wing tilt gross weight increased to 110,000 lbs. for 260 ft. ground roll.

(b) At 35° of wing tilt gross weight increased to 112,000 lbs. for 480 ft. ground roll.

(c) At 25° of wing tilt gross weight increased to 142,000 lbs. for 2,000 ft. ground roll.

This led respectively to weight increases over the VTOL gross weight of 6%, 8% and 36%. Again, this additional weight was realized by virtue of higher speeds and longer runs as the tilt angle was decreased. (see Figure II).

It is emphasized that the above parameters and combinations thereof are not necessarily the optimum but are those that were chosen to show a trend.

When the weight build-up study was completed, the actual take-off distance required for any given gross weight and tilt-angle was calculated by finding the velocity required to equalize the weight, considering all forces acting upon the aircraft at each velocity increment. Once the take-off velocity was established, a step-by-step integration determined the acceleration and distance required to reach this take-off velocity.

B. <u>Distance Required to Clear 50 ft. Obstacle</u>

For each weight and tilt angle the actual take-off was accomplished in close proximity to the stall angle of the wing. For this reason, it was assumed that the airfoil was equipped with a slot and slat combination that would allow the retention of $C_{L_{max}}$ for an additional ten degrees of angle of attack.

If such is the case, the aircraft can be permitted to build-up forward velocity with no application of control required to reduce angle of attack over this 10° increment. Under these conditions, the aircraft will immediately tend to rise once take-off velocity is reached, and it will continue to do so as velocity increases. This, of course, immediately reduces angle of attack and the climb may be continued without encountering wing stall.

An obvious advantage of this approach is that climb may be entered into immediately upon reaching take-off velocity with no transition distance required to accelerate to speed for best climbing angle. This approach is offered as only one possible way of handling this phase of the problem and is not necessarily the optimum. It indicates a trend which should be more thoroughly investigated in the future.

Assuming the climb out to be accomplished in this manner, a step-by-step integration showed the additional ground distance required to climb to 50 ft. after take-off. This portion of the calculation was carried out only for 45 degrees of wing tilt. Figure III shows the total take-off distance required as a function of gross weight for this tilt angle. It may be expected that other values of wing tilt will show a similiar trend

It should be noted that the tilt wing propeller transport aircraft was designed specifically for VTOL operation. With some design changes (such as decreased wing loading, additional flap area, etc.), the STOL performance could be increased substantially with some compromise in VTOL ability. This problem of compromise between VTOL & STOL performance must be investigated more thoroughly for each specific application.

IV. REFERENCES

a) Vertol Aircraft Corporation Report R-75 - "Comparative Study of Various Types of VTOL Transport Aircraft - Interim Summary Report" - dated 12 March 1956.

b) Vertol Aircraft Corporation Report R-76 - "Comparative Study of Various Types of VTOL Transport Aircraft - Configuration Studies Report" - dated 1 May 1956.

c) W-100, "Working Charts for the Computation of Propeller Thrust Throughout the Take-off Range", Gerald L. Desmond and Robert F. Freitag, Bureau of Aeronautics, Navy Department, dated July 1943.

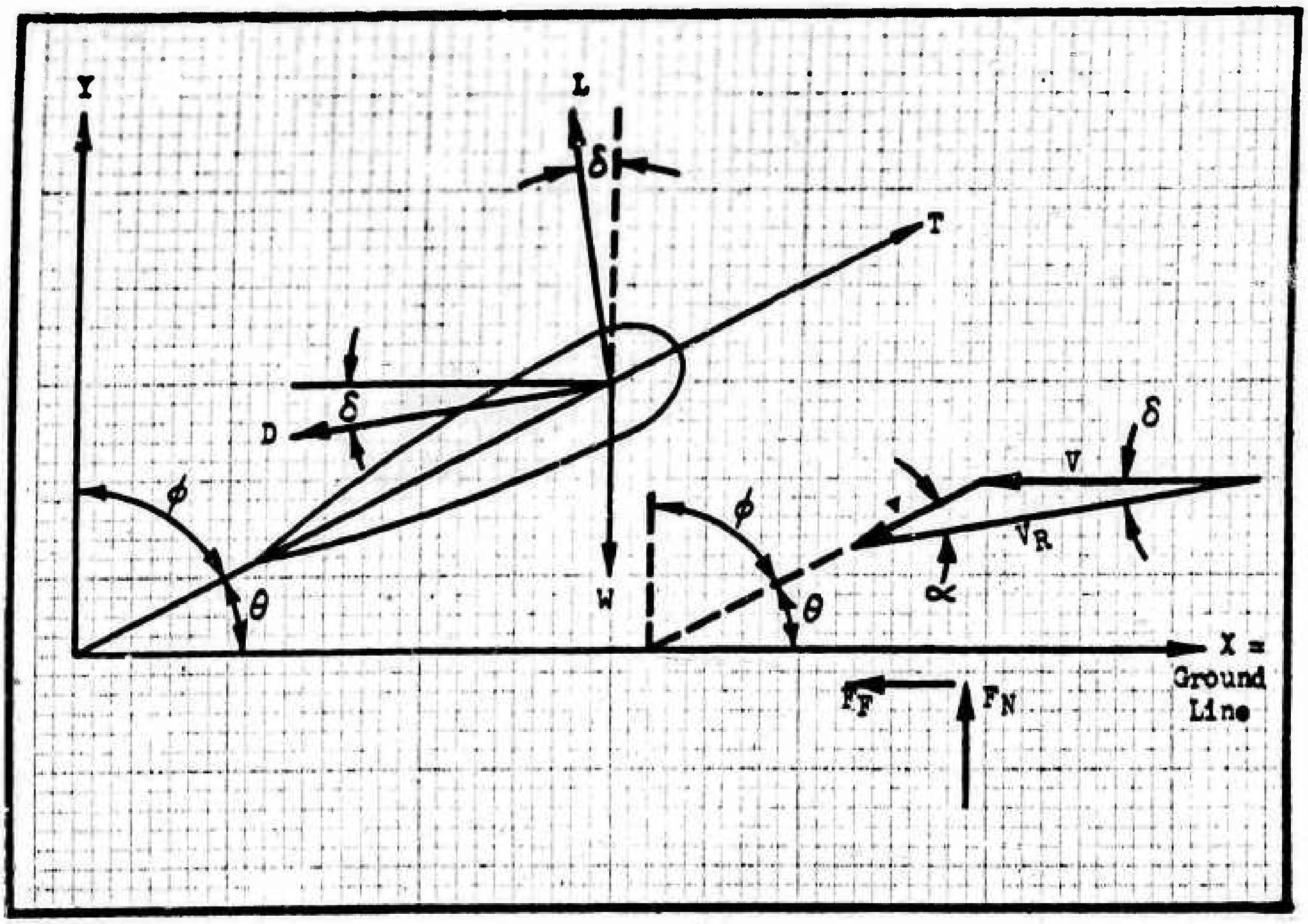
d) Draper, J. W and Kuhn, R. E., "Investigation of the Aerodynamic Characteristics of a Model Wing-Propeller Combination and of the Wing and Propeller Separately at Angles of Attack up to 90°", NACA Technical Note 3304, November 1954.

e) Diehl, W. S., "Engineering Aerodynamics", The Ronald Press Company, July 1940.

f) Wenzinger, C. J. and Harris, T. A., "Wind Tunnel Investigation of an NACA 23012 Airfoil with Various Arrangements of Slotted Flaps," NACA Technical Report 664, 1939.

FIGURE 1

TYPICAL FORCE DIAGRAM



Symbols:

D = Drag
F_F = Friction Force
F_N = Normal Force
L = Lift
T = Thrust Developed by Propeller
v = Velocity Induced by Propeller
V = Forward Velocity
V_R = Resultant Velocity in Slipstream
W = Gross Weight of Aircraft

FIGURE 2

TAKE-OFF DISTANCE VS. GROSS WEIGHT
(GROUND RUN DISTANCE)

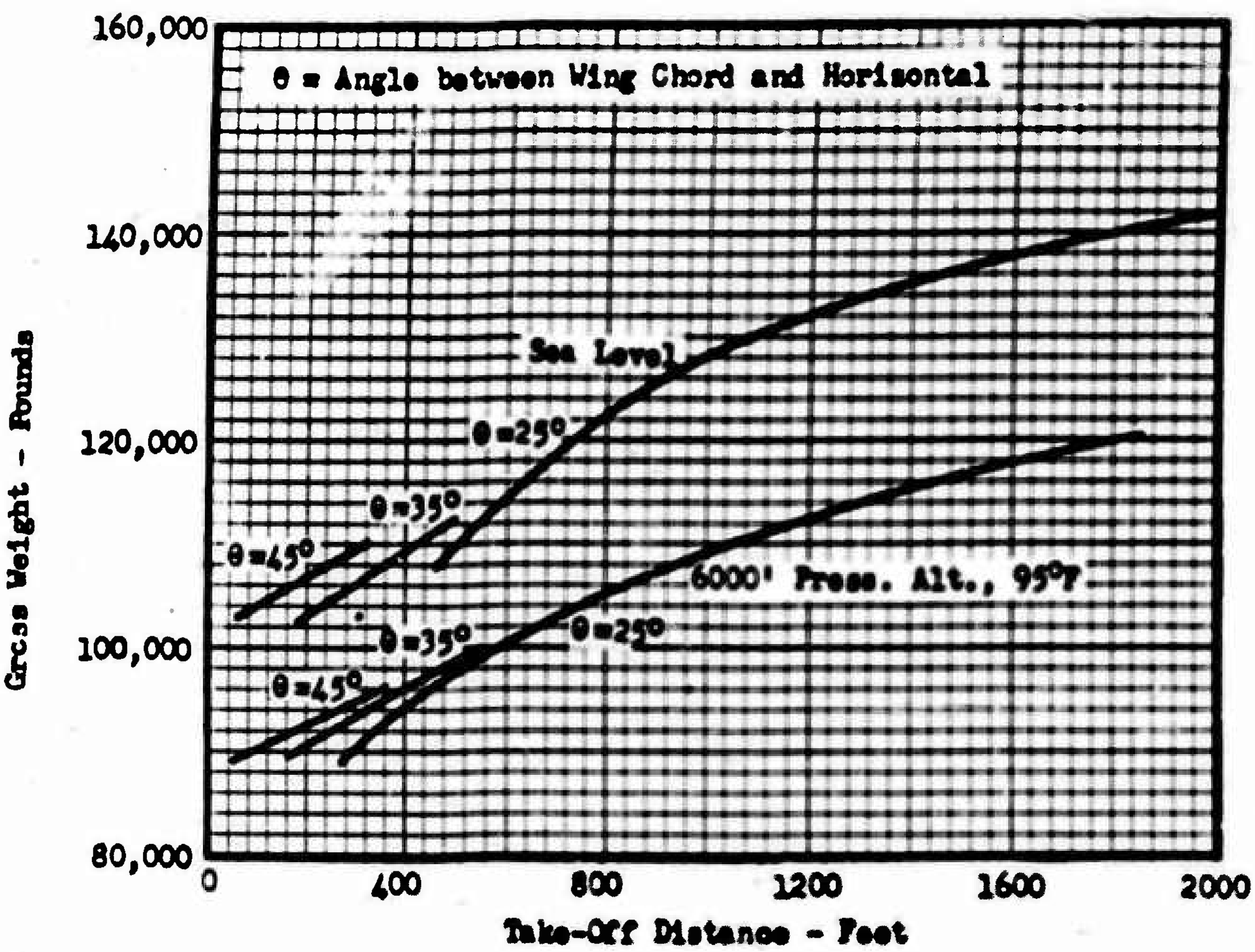
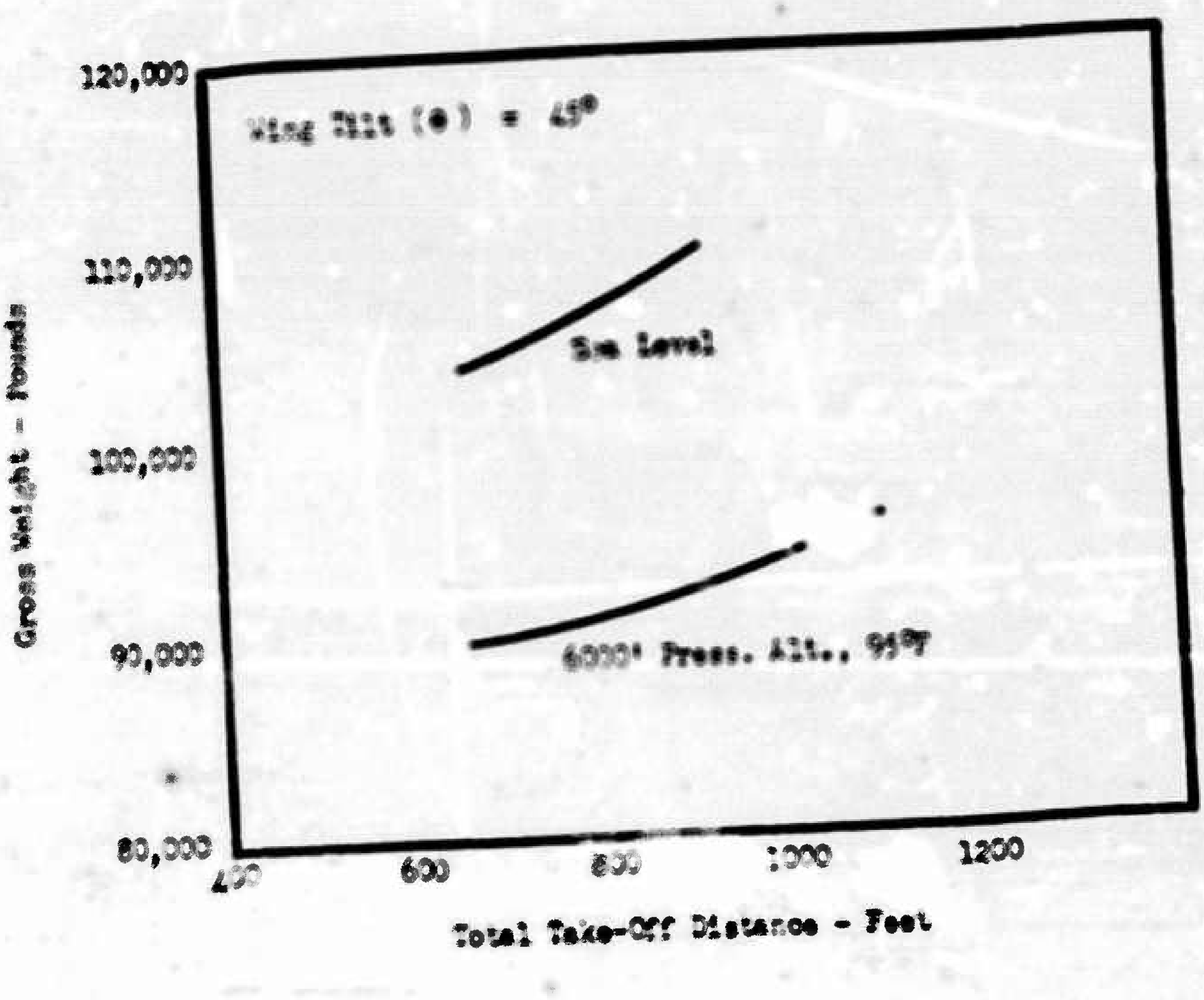


FIGURE 3

TOTAL TAKE-OFF DISTANCE VS GROSS WEIGHT
(TAKE-OFF DISTANCE TO CLEAR 50 FT. OBSTACLE)



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